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ANNUAL LETTER REPORT FOR FY93

1. **Contract Title:** Epitaxial Liff Technology onto
Processed Silicon Foundry Wafers

Number: N00014-93-1-0311

Principal

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Program Manager: Dr. Y. S. Park, ONR, Code 1268

2. **Technical Objectives:** Research the application of liftoff transfer of epitaxial material to foreign substrates including:
- surface chemistry, electrical, mechanical, thermal and optical properties of Van der Waals bonded materials,
 - III-V devices bonded to silicon circuitry and to other substrates with enhanced optical, electrical or thermal properties,
 - integrated optical devices incorporating lifted-off material and/or devices with LiNbO₃ sub 3 λ , glass or other substrates.
3. **Approach:** This effort addresses the need for new technologies which can fully utilize the performance advantages of III-V (GaAs, InGaAs, InGaAsP, and InP) materials for electronic and opto-electronic applications. Specifically, the program is directed at demonstrating the potential of epitaxial liftoff as a technology to enable the realization of "monolithic" optoelectronic devices with the characteristics of epitaxial material. That is, by transfer of epitaxial material to foreign substrates in a form that permits material processing and device fabrication to proceed as though the epitaxial material were grown directly on the substrate. In particular, the chemistry and physical properties of liftoff material structures, the properties of Van der Waals and other bonding techniques for attaching liftoff material to foreign substrates, and the application of lifted off material to single chip optical transmitters/receivers and integrated optical devices will be investigated.
4. **Accomplishments:** Under this contract we have completed at UCLA a contract which began at Bell Communications Research. In our final accomplishment, we integrated AlGaAs hetero-junction bipolar (HBT's) integrated circuits with natural diamond substrates. This increased the power handling capability of the HBT's by a factor three, and made a pronounced improvement in the current-voltage gain curves of the transistors. Contract support began on Feb. 1, 1993, and concluded on Jan. 31, 1994 in this one-year project.
5. **Significance:** Epitaxial Liftoff has become a standard material and device processing technique since this program was begun. Now, one of the few remaining material combinations which was yet to be demonstrated has been proven and worked out: AlGaAs integrated circuits on natural diamond. Due to the device physics of AlGaAs HBT transistors, they are very sensitive to temperature, and were an ideal demonstration model for improved heat sinking.
6. **Future Efforts:** This marks the end of a phase of epitaxial liftoff research. Future efforts will depend on the need for a specific application and specific material combinations.

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7. Listings:

A. Publications:

- i. "Ultra-High Spontaneous Emission Quantum Efficiency, 99.7% Internally and 72% Externally, From AlGaAs/GaAs/AlGaAs Double Heterostructures", I. Schnitzer, E. Yablonovitch, C. Caneau, and T. J. Gmitter, Appl. Phys. Letters. 62, 131 (1993).
- ii. "Epitaxial Liffoff and Related Techniques", by W. K. Chan and E. Yablonovitch to be published in a review volume on opto-electronic integration.
- iii. "30% External Quantum Efficiency from Surface Textured, Thin-Film Light Emitting Diodes", I. Schnitzer, E. Yablonovitch, C. Caneau, T. J. Gmitter, and A. Scherer, Appl. Phys. Letters. 63, 2174 (1993).
- iv. "Epitaxial Liffoff and Bonding of Thin-Film AlGaAs/GaAs Heterojunction Bipolar Transistors Onto Natural Diamond Substrates", V. Arbet-Engels, W. Chang, E. Yablonovitch, G. J. Sullivan, M. K. Swed and M. F. Chang, to be submitted to Appl. Phys. Letters

B. Presentations:

- i. "Ultra-High Spontaneous Emission Quantum Efficiency, 99.7% Internally and 72% Externally, From AlGaAs/GaAs/AlGaAs Double Heterostructures", (delivered by I. Schnitzer), Annual meeting of the IEEE Lasers and Electro-Optics Society, Summer Topical Meetings in Santa Barbara on Opto-Electronic Integration, and Short Wavelength Light Sources.
- ii. "30% External Quantum Efficiency from Surface Textured, Thin-Film Light Emitting Diodes", (delivered by I. Schnitzer), The 1993 Device Research Conference.
- iii. Numerous other presentations at Universities and industrial laboratories.

C. Patents:

- i. "Patterning Method for Epitaxial Liffoff Processing", E. Yablonovitch and T. J. Gmitter, U. S. Patent No. 5,201,996 issued Apr. 13, 1993.

D. Honors/Awards:

- i. E. Yablonovitch received the 1993 IEEE/LEOS W. Streifer Scientific Achivement Award for proposing the benefits of strained semiconductor lasers.

E. Participants:

Dr. Eli Yablonovitch
 Dr. I. Schnitzer
 Dr. Ali Ersen
 Dr. Vincent Arbet Engels
 Dr. Ragu Ranganathan
 Mr. Wei Chang

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